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Final Report

NASA Cooperative Agreement No. NCC1-152

Feasibility Study of the Use of Doppler Global Velocimetry in High Performance Aircraft in Flight

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NASA Technical Officer: James F. Myers, NASA Langley

Award Period: May16, 1991 - May 15, 1992

The cooperative agreement award reads;

"1. NASA will provide Case Western Reserve University (CWRU) with data sets describing the atmospheric particle distributions available in the literature and from NASA sources.

2. CWRU will provide NASA with a first cut performance profile for a flight Doppler global velocimeter by 10/1/91 to serve as a guideline in determining feasibility of the technique for flight application.

3. CWRU and NASA will exchange ideas and discuss research progress and planning by telephone on a regular basis.

4. CWRU will provide NASA with copies of software modules comprising the total DGV simulation as they are completed.

5. NASA will provide CWRU with copies of software modules that are created at NASA to augment the CWRU code.

6. NASA agrees to provide miscellaneous custom-built equipment to aid CWRU research efforts to verify the simulation results experimentally. This equipment includes an Iodine absorption cell. NASA reserves the right to request the return of Government Furnished Property at the completion of this agreement."

Briefly the Doppler Global Velocimeter (DGV) referred to above operates by detecting the Doppler shift in laser light scattered from small particles imbedded in a gas flow, here the flow of air over an aircraft in flight. A laser light sheet is projected onto the region of interest and the

light from this region is simultaneously detected by two video cameras, one directly and the other after passing through a gas absorption cell. See Figure 1. The absorption cell and laser wavelength are arranged so the unperturbed laser light lies part way up the absorption curve for a single line in the cell. Assume for the moment that the wavelengths are set so that the laser is on the longer wavelength side of the absorption line. If there is an upward Doppler shift, the wavelength of the light will be shorter and the light will be moved towards the more absorptive part of the cell. By comparing the intensity received from each visible point in the region from the two cameras, the velocity component along a line bisecting the angle between the laser sheet and the receiver can be measured.
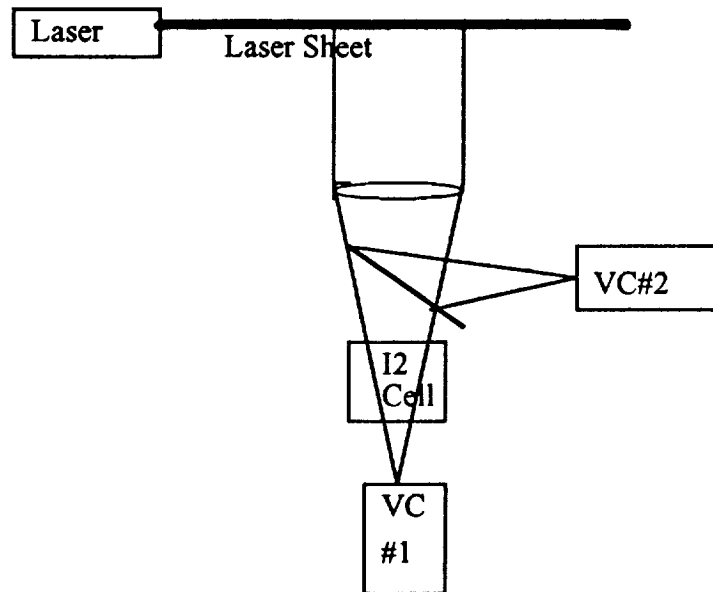

Figure 1

A practical experimental design must explicitly take into account: the absolute intensity of the laser sheet in the region of interest, the size and number density distribution of the scattering particles, the receiving optics and the detection characteristics of the video cameras. In this particular situation, we were constrained by the limitations placed on the laser and receiver by the fact that they must be mounted on an aircraft in such a fashion as to not interfere with flight characteristics. Another important consideration not spelled out in the statement of the cooperative agreement, but made explicit in the proposal was the concept of measurement accuracy. In any photon experiment, the attainable accuracy is a function of the number of photons detected. Here, the situation is complicated by the fact that you must take the ratio of measured intensities in order to get a velocity measurement. The statistical problem to be dealt with is the expected variation in the ratio of two independent random numbers.
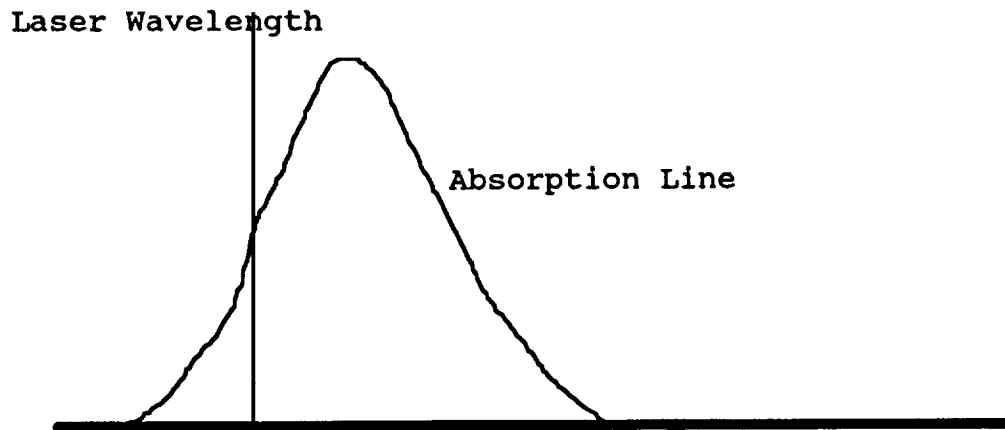
Laser Wavelength

Absorption Line

Figure 2

Calculating the light power in a given region once the laser power and the optics were defined was an easy task and both groups (CWRU and NASA) had generated computer code which essentially gave the same result. The problem of computing the power scattered into the cameras was divided into three parts: calculation of the light scattered *per particle* of a given diameter into a given angle (Mie Codes), estimation of the number density distribution of particle sizes expected in various experimental situations, and computation of the resulting intensity on the photodetectors.

The expressions for calculating the scattered intensity from a spherical dielectric particle were derived the better part of a century ago and computer codes using these expressions were among the first uses of digital computers. Therefore, one would think that incorporating the codes into this program would be nothing more than a matter of finding the appropriate algorithm in the literature, typing it in and debugging the code. Both CWRU and NASA had Mie codes that we had used for years to calculate the scattering from particles with diameters around a micron. We were all surprised when we compared the results of our codes for larger particles of the kind expected for the flight experiment (> 50 μm.) The results were sometimes radically different and neither agreed with some of the results in the literature. We eventually discovered a subtle numerical instability in the calculations that did not appear in the small particle limit. The new, improved Mie code generated after modifications to eliminate the instabilities were given to NASA and used here in the rest of the simulation.

We derived a formula for the probability distribution for the ratio of measurements given two expected intensities. However, this formula turned out to be very difficult to evaluate numerically, so we created a simulator for the detection process in order to examine the accuracy and possible bias of the detection process. The results were passed on to NASA-Langley.

By February, 1992, we had a first cut at complete simulator working at CWRU. It was clear that better modelling was needed for the video detectors and their optics as well as for the scattering particle number density distribution. The code and results from this part of the effort were shared with NASA.

There was close coordination between the CWRU effort and the NASA Langley effort through telephone conversations and several visits to CWRU by people from Langley. By February, the focus of the effort at Langely was shifting toward the details of the photodetection process, especially on the possible problems caused by the coherent laser light, for instance, speckle. Speckle is a phenomena unique to coherent light sources where an object that is uniformly illuminated will appear mottled. The mottling is due to interference between the light from one part of the object interfering with light from nearby parts of the object. This inhomegeneity in the light pattern received can cause an error in the amount of light estimated from a small region of the image, for instance, a pixel on the video camera. There were other problems handling the details of the cameras and the hardware that converted the light signals to digital signals.

CWRU was requested to look at the speckle problem more closely, while Langley would concentrate on the other new photon detection problems. This new concentration displaced the 6th bullet in the cooperative agreement - the experiments.

This change was actually a major change in direction for CWRU since the earlier photodetection model was not detailed enough to deal with speckle. It was, in essence, a model that was extrapolated from incoherent light photodetectors, since we had thought we were only dealing with average intensities. We looked at several approaches including a straight simulation of the propagation of coherent electric fields from sets of simulated particles to each pixel on a video camera. This approach did not seem feasible given the computer resources we had, so we first did a theoretical estimate of the magnitude of the problem expected from speckle. These calculations showed that size of the Rayleigh diffraction from each particle had to be on the order of the size of the individual pixel or larger before speckle would cause an appreciable error in the detectors. Given the camera geometry being used, the first order calculations showed that speckle should not have been a serious problem. However, the problem was not satisfactorily resolved since we ran out of money and time before the problem could be looked at in more detail.

In summary, the vast majority of the cooperative agreement was carried out as negotiated. Due to changes requested by Langley, the experiments discussed in the initial agreement were never carried out.